

WHAT IS CLAIMED IS:

1 1. A pump comprising:
2 a pump body for at least partially defining a pumping chamber and an inlet and
3 an outlet which communicate with the pumping chamber;
4 a piezoelectric actuator situated in the pump body and responsive to a drive
5 signal for pumping fluid between the inlet and outlet; and
6 a drive circuit which applies the drive signal to the piezoelectric actuator as a
7 series of digital pulses.

1 2. The pump of claim 1, wherein the drive circuit further comprises:
2 a pulse generator which generates digital pulses;
1 a converter circuit which uses the digital pulses generated by the pulse generator
2 to produce the series of high voltage charge packets.

1 3. The pump of claim 2, wherein the drive circuit further comprises the
2 piezoelectric actuator, and wherein the piezoelectric actuator, by a capacitive nature of
3 the piezoelectric actuator, integrates the charge packets to shape a waveform of the
4 drive signal.

1 4. The pump of claim 2, wherein the pulse generator comprises a pulsed width
2 modulator (PWM) circuit.

1 5. The pump of claim 4, wherein the pulsed width modulator (PWM) circuit
2 comprises a microcontroller.

1 6. The pump of claim 4, wherein the pulses generated by the pulsed width
2 modulator (PWM) circuit have a pulse width chosen to produced a desired amplitude
3 for the drive signal.

1 7. A method of operating a piezoelectric pump having a piezoelectric actuator
2 situated in a pump body and responsive to a drive signal for pumping fluid between an
3 inlet and an outlet of the pump body, the method comprising:
4 applying a series of digital pulses as the drive signal to the piezoelectric actuator;
5 operating the piezoelectric actuator in response to the drive signal.

1 8. The method of claim 7, further comprising:

2 (1) generating digital pulses;

3 (2) using the digital pulses of step (1) to produce the series of high voltage
4 charge packets.

1 9. The pump of claim 8, further comprising using the piezoelectric actuator to
2 integrate the charge packets and thereby shape a waveform of the drive signal.

1 10. The pump of claim 7, further comprising modulating a pulse width of the
2 digital pulses of step (1) in accordance with a desired waveform for the drive signal.

1 11. A drive circuit which produces a drive signal for a device having a
2 piezoelectric actuator, the piezoelectric actuator forming a part of the drive circuit and
3 serving to shape a waveform of the drive signal.

1 12. The drive circuit of claim 11, wherein the drive circuit comprises:
2 a pulse generator which generates digital pulses;
1 a converter circuit which uses the digital pulses generated by the pulse generator
2 to produce high voltage charge packets; and
3 wherein the piezoelectric actuator, by a capacitive nature of the piezoelectric
4 actuator, integrates the charge packets to shape the waveform of the drive signal.

1 13. The drive circuit of claim 12, wherein the pulse generator comprises a
2 pulsed width modulator (PWM) circuit.

1 14. The drive circuit of claim 13, wherein the pulsed width modulator (PWM)
2 circuit comprises a microcontroller.

1 15. The drive circuit of claim 13, wherein the digital pulses generated by the
2 pulsed width modulator (PWM) circuit have a pulse width chosen to produced a desired
3 amplitude for the drive signal.

1 16. The drive circuit of claim 12, wherein the converter circuit comprises a
2 flyback circuit.

1 17. The drive circuit of claim 16, wherein the flyback circuit produces
2 potentials that are bipolar with respect to an electrical ground.

1 18. The drive circuit of claim 12, further comprising a filter for filtering
2 components of the charge packets produced by the converter circuit.

1 19. The drive circuit of claim 12, wherein a frequency of the charge packets
2 produced by the converter circuit is greater than an ability of the piezoelectric actuator
3 to mechanically respond.

1 20. The drive circuit of claim 19, wherein the frequency of the charge packets
2 produced by the converter circuit is chosen to be greater than an ability of the
3 piezoelectric actuator to mechanically respond so that the charge packets produced by
4 the converter circuit do not contribute to one of mechanical inefficiency and noise in
5 the piezoelectric actuator.

1 21. The drive circuit of claim 12, wherein the charge packets comprise positive
2 and negative pulses, and wherein the piezoelectric actuator integrates the positive
3 pulses and the negative pulses to yield a drive field that approximates a sine wave.

1 22. The drive circuit of claim 12, wherein neither a bridge switching circuit nor
2 a charge storage circuit are connected between the converter circuit and the
3 piezoelectric actuator.

1 23. A pump comprising:
2 a pump body for at least partially defining a pumping chamber and an inlet and
3 an outlet which communicate with the pumping chamber;
4 a piezoelectric actuator situated in the pump body and responsive to a drive
5 signal for pumping fluid between the inlet and outlet; and
6 a drive circuit which produces the drive signal, the piezoelectric actuator
7 forming a part of the drive circuit and serving to shape a waveform of the drive signal.

1 24. The pump of claim 23, wherein the drive circuit comprises:
2 a pulse generator which generates digital pulses;

3 a converter circuit which uses the digital pulses generated by the pulse generator
4 to produce high voltage charge packets; and

5 wherein the piezoelectric actuator, by a capacitive nature of the piezoelectric
6 actuator, integrates the charge packets to shape the waveform of the drive signal.

1 25. The pump of claim 24, wherein the pulse generator comprises a pulsed
2 width modulator (PWM) circuit.

1 26. The pump of claim 24, wherein the pulsed width modulator (PWM) circuit
2 comprises a microcontroller.

1 27. The pump of claim 24, wherein the digital pulses generated by the pulsed
2 width modulator (PWM) circuit have a pulse width chosen to produced a desired
3 amplitude for the drive signal.

1 28. The pump of claim 24, wherein the converter circuit comprises a flyback
2 circuit.

1 29. The pump of claim 24, wherein the flyback circuit produces potentials that
2 are bipolar with respect to an electrical ground.

1 30. The pump of claim 24, further comprising a filter for filtering components
2 of the charge packets produced by the converter circuit.

1 31. The pump of claim 24, wherein a frequency of the pulses produced by the
2 converter circuit is greater than an ability of the piezoelectric actuator to mechanically
3 respond.

1 32. The pump of claim 31, wherein the frequency of the charge packets
2 produced by the converter circuit is chosen to be greater than an ability of the
3 piezoelectric actuator to mechanically respond so that the charge packets produced by
4 the converter circuit do not contribute to one of mechanical inefficiency and noise in
5 the piezoelectric actuator.

1 33. The pump of claim 24, wherein the charge packets comprise positive
2 pulses and negative pulses, and wherein the piezoelectric actuator integrates the
3 positive pulses and the negative pulses to yield a drive field that approximates a sine
4 wave.

1 34. The pump of claim 24, wherein neither a bridge switching circuit nor a
2 charge storage circuit are connected between the converter circuit and the piezoelectric
3 actuator.

1 35. A pump comprising:
2 a pump body for at least partially defining a pumping chamber and an inlet and
3 an outlet which communicate with the pumping chamber;
4 a piezoelectric actuator situated in the pump body and responsive to a drive
5 signal for pumping fluid between the inlet and outlet;
6 a power supply; and
7 a drive circuit which is powered by the power supply and which produces the
8 drive signal;
9 wherein the piezoelectric actuator serves as a voltage storage device for the
10 power supply.

1 36. The pump of claim 35, wherein the drive circuit comprises:
2 a pulse generator which generates digital pulses;
1 a converter circuit which uses the digital pulses generated by the pulse
2 generator to produce high voltage charge packets; and
3 wherein the piezoelectric actuator, by a capacitive nature of the
4 piezoelectric actuator, integrates the charge packets to shape a waveform of the drive
5 signal.

1 37. The pump of claim 36, wherein the pulse generator comprises a pulsed
2 width modulator (PWM) circuit.

1 38. The pump of claim 36, wherein the charge packets comprise positive
2 pulses and negative pulses, and wherein the piezoelectric actuator integrates the
3 positive pulses and the negative pulses to yield a drive field that approximates a sine
4 wave.

1 39. The pump of claim 37, wherein the digital pulses generated by the pulsed
2 width modulator (PWM) circuit have a pulse width chosen to produced a desired
3 amplitude for the drive signal.

1 40. A method of operating a device having a piezoelectric actuator which is
2 responsive to a drive signal, the method comprising:

3 (1) generating digital pulses;

4 (2) using the digital pulses of step (1) to produce high voltage charge packets;

5 and

6 (3) using the piezoelectric actuator to integrate the charge packets and thereby
7 shape a waveform of the drive signal.

1 41. The method of claim 40, further comprising using a pulsed width modulator
2 (PWM) circuit to generate the digital pulses of step (1).

1 42. The method of claim 40, further comprising generating the digital pulses of
2 step (1) to have a pulse width chosen to produced a desired amplitude for the drive
3 signal.

1 43. The method of claim 40, further comprising using a flyback circuit to
2 produce the charge packets.

1 44. The method of claim 43, further comprising using the flyback circuit to
2 produce potentials that are bipolar with respect to an electrical ground.

1 45. The method of claim 40, further comprising filtering components of the
2 charge packets.

1 46. The method of claim 40, further comprising setting a frequency of the
2 charge packets to be greater than an ability of the piezoelectric actuator to mechanically
3 respond.

1 47. The method of claim 46, further comprising setting the frequency of the
2 charge packets to be greater than an ability of the piezoelectric actuator to mechanically

3 respond so that the charge packets do not contribute to one of mechanical inefficiency
4 and noise in the piezoelectric actuator.

1 48. The method of claim 40, wherein the charge packets comprise positive
2 pulses and negative pulses, and wherein the piezoelectric actuator integrates the
3 positive pulses and the negative pulses to yield a drive field that approximates a sine
4 wave.

1 49. A method of operating a device having a piezoelectric actuator which is
2 responsive to a drive signal, the method comprising:
3 using a power supply to power a drive circuit which generates the drive signal,
4 the drive signal comprising charge pulses;
5 using the piezoelectric actuator to integrate the charge packets into an electric
6 field;
7 using the piezoelectric actuator to store charge and thereby serve as a charge
8 storage device for the power supply.

1 50. The method of claim 49, further comprising using a pulsed width modulator
2 (PWM) circuit to generate the charge pulses.

1 51. A piezoelectrically-operated apparatus comprising:
2 a piezoelectric actuator which is responsive to a drive signal; and
3 a drive circuit which applies the drive signal to the piezoelectric actuator as a
4 series of digital pulses.

1 52. The apparatus of claim 51, wherein the drive circuit further comprises:
2 a pulse generator which generates digital pulses;
1 a converter circuit which uses the digital pulses generated by the pulse generator
2 to produce the series of high voltage charge packets.

1 53. The apparatus of claim 52, wherein the drive circuit further comprises the
2 piezoelectric actuator, and wherein the piezoelectric actuator, by a capacitive nature of
3 the piezoelectric actuator, integrates the charge packets to shape a waveform of the
4 drive signal.

1 54. The apparatus of claim 52, wherein the pulse generator comprises a pulsed
2 width modulator (PWM) circuit.

1 55. The apparatus of claim 54, wherein the pulsed width modulator (PWM)
2 circuit comprises a microcontroller.

1 56. The apparatus of claim 54, wherein the pulses generated by the pulsed
2 width modulator (PWM) circuit have a pulse width chosen to produced a desired
3 amplitude for the drive signal.

1 57. A piezoelectrically-operated apparatus comprising:
2 a piezoelectric actuator which is responsive to a drive signal; and
3 a drive circuit which produces the drive signal, the piezoelectric actuator
4 forming a part of the drive circuit and serving to shape a waveform of the drive signal.

1 58. The apparatus of claim 57, wherein the drive circuit comprises:
2 a pulse generator which generates digital pulses;
3 a converter circuit which uses the digital pulses generated by the pulse generator
4 to produce high voltage charge packets; and
5 wherein the piezoelectric actuator, by a capacitive nature of the piezoelectric
6 actuator, integrates the charge packets to shape the waveform of the drive signal.

1 59. The apparatus of claim 58, wherein the pulse generator comprises a pulsed
2 width modulator (PWM) circuit.

1 60. The apparatus of claim 58, wherein the pulsed width modulator (PWM)
2 circuit comprises a microcontroller.

1 61. The apparatus of claim 58, wherein the digital pulses generated by the
2 pulsed width modulator (PWM) circuit have a pulse width chosen to produced a desired
3 amplitude for the drive signal.

1 62. The apparatus of claim 58, wherein the converter circuit comprises a
2 flyback circuit.

1 63. The apparatus of claim 58, wherein the flyback circuit produces potentials
2 that are bipolar with respect to an electrical ground.

1 64. The apparatus of claim 58, further comprising a filter for filtering
2 components of the charge packets produced by the converter circuit.

1 65. The apparatus of claim 58, wherein a frequency of the pulses produced by
2 the converter circuit is greater than an ability of the piezoelectric actuator to
3 mechanically respond.

1 66. The apparatus of claim 65, wherein the frequency of the charge packets
2 produced by the converter circuit is chosen to be greater than an ability of the
3 piezoelectric actuator to mechanically respond so that the charge packets produced by
4 the converter circuit do not contribute to one of mechanical inefficiency and noise in
5 the piezoelectric actuator.

1 67. The apparatus of claim 58, wherein the charge packets comprise positive
2 pulses and negative pulses, and wherein the piezoelectric actuator integrates the
3 positive pulses and the negative pulses to yield a drive field that approximates a sine
4 wave.

1 68. The apparatus of claim 58, wherein neither a bridge switching circuit nor a
2 charge storage circuit are connected between the converter circuit and the piezoelectric
3 actuator.

1 69. A drive circuit which produces a drive signal for a piezoelectric actuator, the
2 drive circuit comprising:
3 a source of digital pulses;
4 a transformer;
5 power switching element which receives the digital pulses and selectively
6 applies current to the transformer;
7 means for using an electromotive force generated by parasitic capacitance of the
8 transformer providing to high voltage bipolar output to the piezoelectric actuator.

- 1 70. The apparatus of claim 69, wherein the transformer is has only one
- 2 secondary winding with no taps.